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Navigation and wayfinding in learning spaces in 3D virtual worlds

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PART ONE

HUMAN- COMPUTER INTERACTION

1

NAVIGATION AND WAYFINDING IN LEARNING SPACES IN 3D VIRTUAL WORLDS

Shailey Minocha and Christopher Hardy

Three-dimensional (3D) virtual worlds are simulated environments, often managed over the Web and facilitated by networked computers, which users can “inhabit” and interact in via their graphical self-representations known as “avatars.” In a 3D virtual world, the users experience others as being present in the same environment even though they may be geographically distributed. Users converse in real time through gestures, audio, text-based chat, and instant messaging (Meadows, 2008). Three-dimensional virtual worlds support synchronous communication and collaboration more effectively than 2D web-based environments by extending the user’s ability to employ traditional communication cues of face-to-face interactions, such as gestures and voice, and having a better sense of presence and place (Bronack, Cheney, Riedl, & Tashner, 2008). Virtual worlds, therefore, offer an awareness of space, distance, and coexistence of other participants similar to real life spaces giving a sense of environment, geography, and terrain (Bell, 2008).

There are several 3D virtual worlds that are being employed for gaming, organizing meetings and events, marketing, e-commerce, training through role-playing and games, in education, and for conducting research on crowd behaviour or social science experiments. Examples of 3D virtual worlds include games such as World of Warcraft (<http://eu.battle.net/wow/en>), Runescape (<http://www.runescape.com>), and Entropia Universe (<http://www.entropiauniverse.com>) as well as other multi-user virtual environments such as Second Life (<http://www.secondlife.com>) and those based on open-source software

like OpenSim (<http://www.opensimulator.org>)¹ or web browser-based platforms such as AvayaLive Engage (<http://engage.avayalive.com/Engage>) and Jibe (<http://www.reactiongrid.com>). In this chapter, our focus is on Second Life and the design of learning spaces within it. Unlike massively multiplayer online role-playing games (MMORPGs) like World of Warcraft that have a scripted plot or storyline, Second Life is not a “game” per se. The content and narrative in Second Life are created and owned by the users.

Virtual worlds such as Second Life offer new opportunities for teaching in immersive and creative spaces. In distance education and online learning courses, Second Life can facilitate socialization and collaborative activities, or in blended learning environments it can complement face-to-face teaching; for example, activities that may not be feasible or are too difficult to carry out in real-life settings such as training students on warehouse management can be done within the virtual world (see “A Day in the Life of a 3D Warehouse” at <http://www.ciltglobal.org/sl>).

However, learning and teaching in virtual worlds poses a number of challenges for educators and designers. In terms of pedagogical theories, moving from established transmissive theories of learning such as behaviourism and cognitivism (Felix, 2005) to participatory ones such as social constructivism in virtual worlds can be challenging (Reeves & Minocha, 2011). Further, the design of 3D learning spaces to match with pedagogical activities, the extent of the designs’ realism, and the influence of the design of learning spaces on student learning and engagement also raises interesting issues.

There is a lack of published research on the design guidelines of learning spaces in virtual worlds. Therefore, when institutions aspire to create learning spaces in Second Life, there are few studies or guidelines to inform them except for individual case studies such as in Lucia, Francesse, Passero, and Tortora (2008), or in Rapanotti, Minocha, Barroca, Boulous, and Morse (2011). The Design of Learning Spaces in 3D Virtual Environments (DELVE) project (<http://webarchive.nationalarchives.gov.uk/20140702233839/http://www.jisc.au.uk/whatwedo/programmes/elearning/ltig/delve.aspx>), funded by the Joint Information Systems Committee in the UK, was one of the first initiatives that identified through empirical investigations the usability problems associated with learning spaces in virtual worlds and the potential impact on student experience. The findings of the DELVE project (e.g., Minocha & Reeves, 2010a,

¹ Examples of OpenSim-based worlds can be found at http://www.opensimulator.org/wiki/Grid_List

2010b) revealed that applying architectural principles of real-world designs to virtual worlds as discussed by Charitos (1997) and Dickey (2004) may not be sufficient. In fact, design principles from urban planning (e.g., Lynch, 1960), Human–Computer Interaction (HCI), web usability, geography, and psychology influence the design of learning spaces in virtual worlds.

In DELVE, Minocha and Reeves (2010a) derived several usability guidelines: form should follow function, that is, that the shape of a building or object should be primarily based upon its intended function or purpose; use real-world metaphors such as mailboxes for students to leave messages, or search pods similar to real-world information kiosks; consider realism for familiarity and comfort; design for storytelling; or design to orient the user at the landing point, et cetera. However, the investigations in DELVE identified that the key usability problems experienced by users in 3D learning spaces are related to navigation and wayfinding. For example, in Figure 1.1, there are no directional signs at an intersection in a 3D learning space related to genetics in Second Life.

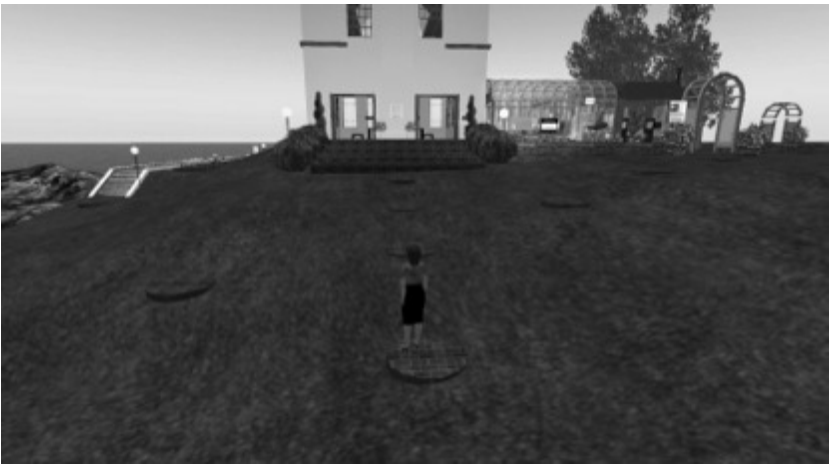


Figure 1.1 The problem of navigation and wayfinding. Picture courtesy of the Genome Island in Second Life.

In this chapter, we report on the Navigation and Wayfinding (NAVY) project which builds on the findings of the DELVE project. As the most commonly used virtual world for education, Second Life was the logical choice for conducting the NAVY project research. Based upon empirical investigations of a number of islands in Second Life (an island is a space which is analogous to a website

in a 2D environment) involving user-based studies, heuristic evaluations, and iterative reviews of the heuristics by usability experts, we have derived over 200 guidelines for the design of learning spaces in virtual worlds.

Background

Based on their interviews with educators, Reeves and Minocha (2011) reported several interpretations of a learning space in a virtual world: (a) a space where an educator-led learning activity occurs; (b) open spaces such as a sandbox within an island in Second Life; (c) an entire island where learning can take place through socialization, in formal learning activities, and also while networking; and (d) the whole of Second Life. In the research we report on in this chapter, a learning space is defined as an island in Second Life designed to facilitate learning activities, and support self-paced, collaborative, informal, and formal learning. An educational institution's island in Second Life can provide a dedicated environment for learning, which helps to ensure a sense of belonging and purpose for students. This sense of belonging is particularly significant for distance education students whomay have not visited a physical campus of their institution in real life.

Navigation and Wayfinding

Volbracht (1999) defined navigation as the process by which people control their movement using environmental cues and aids such as maps so that they can achieve their goals without being lost, and wayfinding as the process of determining the strategy, direction, and course needed to reach a desired destination. Wayfinding doesn't involve movement; it is the cognitive element of navigation and the process of determining and following a path or route between an origin and a destination (Golledge, 1999). Darken and Peterson (2001) defined navigation as the aggregate task of wayfinding and motion, where wayfinding is the cognitive element of navigation, and motion or travel is the motoric element.

Navigation and Wayfinding in Real-World Environments

Arthur and Passini (1992) described three stages of wayfinding in real-world contexts: decision- making, executing decisions, and information processing. In unfamiliar settings, people need information at every stage:

- For decision-making, that is how the setting is organized, where they are in it, and where their destination is.
- To execute decisions, such as, information directing them to their destination.

- To conclude the decision-execution process: identifying that they have reached their destination.

Arthur and Passini (1992) identified two major components of wayfinding design: spatial planning and environmental communication. Spatial planning determines the location of entrances, exits, and major destinations. From a wayfinding perspective, spatial planning comprises three stages:

- Identifying the constituent spatial units
- Grouping spatial units into destinations
- Organizing and linking the units and zones.

Arthur and Passini (1992) introduced the second component of wayfinding design as environmental communication. Achieving an accurate cognitive map of the spaces in an environment and the routes for navigating is essential for effective orientation and movement. Spatial knowledge helps a user to construct a cognitive map (internal representation) of the environment. For example, landmarks give a place identity and also help people to provide directions (e.g., the Eiffel Tower in Paris, or Big Ben in London). Landmarks are salient cues providing information on a person's location during wayfinding. Paths, maps, and signage such as directional signs, identifications, and signs at the decision points along the paths also enhance wayfinding performance (Arthur & Passini, 1992). However, information required to solve a wayfinding problem isn't determined by the environmental setting alone. It is also influenced by a person's preference for a certain type of information—whether it is linear and sequential, as one might find on signs, or whether it is spatial and global, such as information emanating from the setting itself. These two wayfinding styles are not exclusive, as most people use both. Therefore, it is important that spatial and linear information coexist to allow for both wayfinding styles.

Navigation and Wayfinding in Virtual Worlds

Charitos (1997) focused on the design of virtual worlds from an architectural perspective. He considered the significance of spatial elements in virtual environments to inform human wayfinding and suggested an architectural way of thinking may prove useful for developing novel ways of designing virtual environments. He discussed two types of components that can aid navigation in virtual worlds: objects and elements of space. Landmarks, signs, boundaries, and thresholds are referred to as objects, whereas places, paths, intersections, and domains (districts) are elements of space. Charitos made no attempt to test

the effectiveness of these components on wayfinding performance, and Conroy-Dalton (2002) critiqued his approach, stating that it remains conceptual.

Dickey (2004) applied Charitos' (1997) architectural perspective of virtual world design in her investigation into the design of educational virtual environments. She discovered that the inclusion and careful placement of architectural objects and elements aided student navigation and wayfinding through both the virtual environment and the materials. Therefore, the use of architectural objects and elements holds much relevance for the design of virtual worlds. Dickey acknowledged the limitations of her approach to the design of virtual environments, stating that real-world environmental issues such as the weather and erosion are not applicable to virtual worlds, so there may be occasions when an architectural perspective will not suffice. However, she proposed that an architectural model using the components (landmarks, signs, etc.) identified by Charitos could be an effective model for the design of educational virtual worlds.

Steck and Mallot (2000) provided explicit evidence about landmarks when discussing the role of local and global landmarks in the navigation of virtual environments. They performed an experiment in "Hexatown," a virtual environment comprising a hexagonal grid of streets and junctions, where each junction was identified by the presence of a local landmark such as a telephone box. They also used global landmarks in the form of a television tower, skyline, and hilltop. Their research showed that different participants adopt different wayfinding strategies. Some used only local landmarks for decision-making, some solely global landmarks, while others used a combination of the two, and still others alternated between them. Vinson (1999) concluded that landmarks indicate position and orientation, and contribute to the development of spatial knowledge. Using distinctive landmarks facilitates users' abilities to acquire and apply spatial knowledge, enabling them to navigate virtual environments.

Darken and Sibert (1996) concluded that large-scale virtual environments require structure in order for users to effectively navigate in them. The real-world principles of organizational and environmental design identified by Darken (1995) can provide such a structure: for example, by dividing large-scale worlds into smaller distinct parts, organizing these parts under a simple organizational principle, and providing frequent directional clues.

Figure 1.2 provides an example of structure: an area is divided into smaller sections (districts) and augmentation using directional indicators and maps is provided; something commonly implemented within Second Life islands.

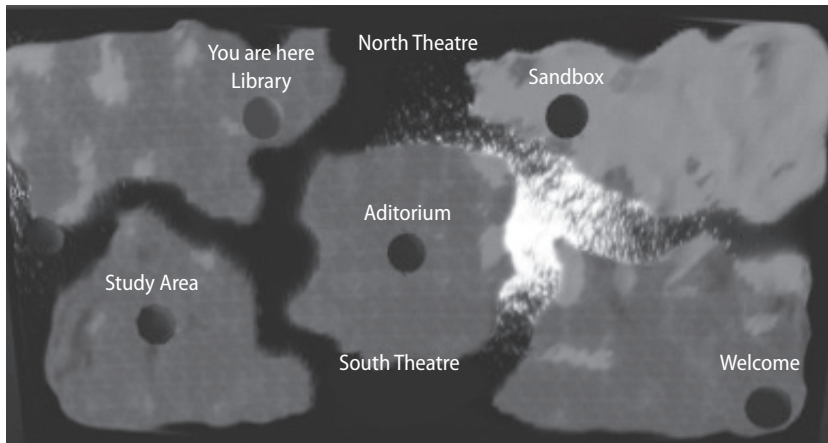


Figure 1.2 A map of the deep|think Island in Second Life, showing its division into five sections. Picture courtesy of the deep|think Island, Department of Computing, The Open University, UK.

Efficient navigation is a problem (Sadeghian, Kantardzic, Lozitskiy, & Sheta, 2006), especially in large-scale virtual worlds where a navigator's viewpoint cannot encompass the entire environment (Vinson, 1999). If navigation is difficult, users will have a bad perception of the virtual world's usability (Sebok, Nystad, & Helgar, 2004). Navigational difficulties in virtual worlds originate from various factors. A general lack of familiarity is one factor (Burigat & Chittaro, 2007) that is not surprising, given a user will always be unfamiliar when first encountering a particular space (Vinson, 1999). Sayers (2004) stated that a user's lack of familiarity with the environment can result in disorientation, which can cause anxiety and discomfort (Darken & Peterson, 2001). Wayfinding problems may occur in virtual worlds because they generally have less sensory (visual, auditory, or motoric) detail than real-world environments (van Dijk, op den Akker, Nijholt, & Zwiers, 2003). Heino, Cliburn, Rilea, Cooper, and Tachkov (2010) state the key issue relating to navigation and wayfinding: if users cannot find their way to a destination, they cannot use the virtual world for its desired purpose.

Darken and Sibert (1996) found that augmentations provided by directional indicators, for example, landmarks, maps, and paths can enhance wayfinding performance. Wayfinding tasks generally require the navigator to be able to conceptualize an entire space. Task performance improves with an increased spatial knowledge of the environment. In summarizing their research they stated that, despite the importance of navigation in virtual worlds, support

for effective navigation is often overlooked in the design process. They attributed this shortcoming to the lack of guidance. Thus providing guidance for designers of virtual worlds to aid navigation and wayfinding has been the focus of our research.

Impact on Student Engagement

We define student engagement as the time, energy, and resources students devote to activities designed to enhance learning within an educational context. Navigation and wayfinding problems in learning spaces can adversely influence student engagement and learning because they hinder a student's ability to locate study resources. In Figure 1.3, the student teleports to the Library area on the deep|think Island and finds a board stating "Library Welcome Area." When trying to find the library, the student will most likely decide to make a right turn into the Library Welcome Area. This decision is incorrect; the library areas are the distant cone-roofed buildings on the left.

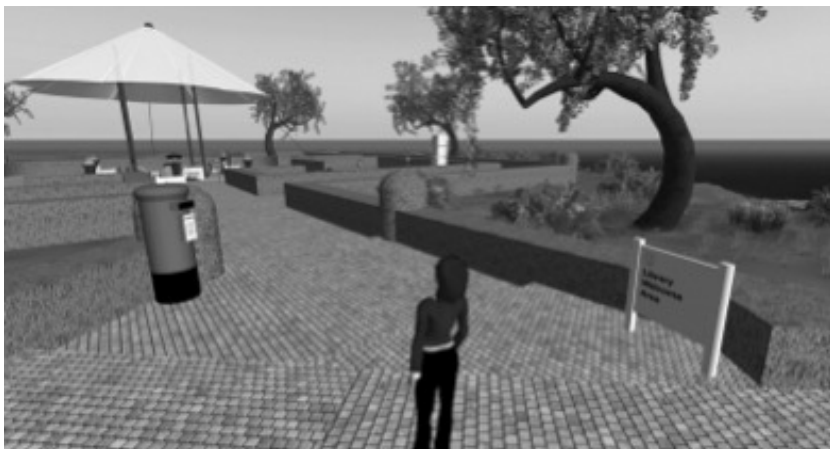


Figure 1.3 Finding the way to the library. Picture courtesy of the deep|think Island, Department of Computing, The Open University, UK.

The research in the DELVE project showed that users come to a 3D virtual world with mental models based on their real-life experiences and interactions with websites. In the NAVY project, our aim was to investigate the impact of obstacles in navigation and wayfinding on student experience and how the design aspects related to website navigation (e.g., design of the home page, organization of links, and so on) can complement real-world navigation (e.g.,

maps, paths, landmarks, etc.) to influence the design of learning spaces in virtual worlds.

Research Methodology

Our empirical investigations involved the following (Table 1.1):

- Heuristic evaluations: a usability inspection technique which involves a usability or an HCI expert evaluating a user interface design of a computer system (e.g., website, mobile phone) with respect to usability guidelines to determine the aspects of the user interface that do not adhere to the guidelines and could potentially cause obstacles or usability problems in user–system interaction (Stone, Jarrett, Woodroffe, & Minocha, 2005);
- Structured or semi-structured interviews;
- User observations with think-aloud protocols and post-observation discussions (Stone et al., 2005);
- Document analysis.

Three types of participants were involved in the research: designers of learning spaces in Second Life, Second Life educators, and students who were experienced users of Second Life.

Table 1.1 Summary of NAVY’s Methodology

Technique	Who was involved?	What did it involve?
Heuristic evaluations	two usability experts conducted the evaluations; a guidelines expert from the industry assessed the heuristics as they were being iteratively developed and consolidated	evaluating 11 islands in Second Life with respect to heuristics to check the adherence or non-adherence to the designs with respect to the heuristics
Structured or semi-structured interviews	Second Life educators and designers of learning spaces; a tour guide in Second Life	conducting interviews within Second Life (inworld interviews) similar to the way one would done in a face-to-face setting; one of the educators chose to send us the inputs by email; 3 designers, 3 educators, and 1 tour guide participated

Technique	Who was involved?	What did it involve?
User observations	students familiar with Second Life and who had carried out learning activities in Second Life	10 students were observed conducting learning activities on 4 islands; post-observation discussions were carried out to enable the participants to reflect on their experiences and to share navigation strategies with the researcher (observer)
Document analysis	papers related to the design of islands that we were evaluating, any associated blogs, wikis, videos (transcripts)	analyzing the documents and related multimedia resources to determine the background of the island, purpose of the island and the audience; which kinds of learning activities it supports

Developing the Heuristics and Evaluation Worksheet

First, we compiled an initial set of heuristics from the literature, for example:

- Architectural principles of real-world designs (Arthur & Passini, 1992);
- System checklists (e.g., Pierotti, 1995);
- Participatory heuristic evaluations (Muller, Matheson, Page, & Gallup, 1998);
- Heuristic evaluations of computer games (e.g., Isbister & Schaffer, 2008; Sutcliffe & Gault, 2004);
- Web usability (e.g., Nielsen, 2000).

We identified ten usability heuristic categories (HCs): eight from Nielsen (2000), one from Sutcliffe and Gault (2004), and one from Muller et al. (1998). These HCs included visibility of system status, match between the system and the real world, user control and freedom, consistency and standards, recognition rather than recall, aesthetic and minimalist design, help and documentation, pleasurable and respectful interaction with the user, navigation and orientation support, and error prevention. By adapting the original descriptions, the definitions of the individual HCs were developed in order to align the “new” definitions to the context of 3D learning spaces. Then we assigned relevant heuristics to the most appropriate HC and compiled in a spreadsheet (we called it an “evaluation worksheet”).

We reviewed and refined the evaluation worksheet of heuristics iteratively throughout the project. Enhancements to the evaluation worksheet included:

- New columns, added for the rationale for inclusion and the source (source implies a reference to the heuristic, a published paper or book).
- A practitioner guidelines expert assessed the heuristics in the early stages of development. After their feedback we added new columns: implicit knowledge of an evaluator and design resource (e.g., where a designer could find out about colours or information on design of maps).
- Within the ten heuristic categories, we ordered the heuristics so that designers could prioritize their evaluations if they did not have the resources to evaluate every heuristic.
- Two usability experts iteratively evaluated the heuristics and we incorporated their feedback into the improvement (e.g., clarity, re-wording) of the individual heuristics.
- We added additional heuristics to cater to usability defects arising from heuristic evaluations, and which weren't in the existing heuristics.
- We removed heuristics if deemed inappropriate; for example, if they duplicated existing heuristics, weren't relevant, or couldn't be evaluated without quantitative analysis such as measuring student immersion or satisfaction.
- The heuristic category HC9, "Navigation and orientation support" which was the focus of the NAVY project, was enhanced by literature review (e.g., Arthur & Passini, 1992; Darken, 1995; Dondlinger & Lunce, 2009; Steck & Mallot, 2000). We ordered the heuristics in this category as per the three stages of the wayfinding process.

The final structure of the evaluation worksheet is shown in Table 1.2.

Table 1.2 Structure of the Evaluation Worksheet

Column heading	Column content
Identifier	A unique identifier for the heuristic with two parts: e.g., HC1 to HC10 for the 10 categories (1 to 10).
Heuristic category name	A category name in which related heuristics are grouped together, e.g., the "Navigation and orientation support" category contains heuristics relating to architectural landmarks maps, paths, and signs. A category can be considered a general principle for usability design.

Column heading	Column content
Heuristic	A sub-division or low-level rule of a heuristic category. For example, heuristic HC9.5 states, "Is the text on maps easy to read?"
Rationale for inclusion	This provides the logic for including the heuristic. For example for HC9.5, the rationale was that if text on maps is not easy to read, it may be misunderstood or not read at all.
Implicit knowledge of the evaluator	This identifies the knowledge the evaluator required to assess the heuristic. For example, in order to evaluate the design of a map in terms of HC9.5, an evaluator was expected to be aware of how text can be formatted to aid readability; one guideline is that UPPER CASE text is slower and hence more difficult to read compared to Proper Case text.
Example	Two examples are provided for each heuristic: (a) An example in which a heuristic is violated, i.e., a usability defect; (b) An example that demonstrates positive adherence to the heuristic, i.e., a positive aspect.
Figure	Two figures are provided for each heuristic to demonstrate: (a) a usability defect, and (b) a positive aspect.
Source	This is the origin of the heuristic, e.g., a literature source, a user observation session, a heuristic evaluation, or through general exploration of Second Life islands.
Design resource	This is a URL (web resource) where a designer can find more detailed guidance for evaluating a heuristic in order to supplement their implicit knowledge required for the heuristic (e.g., a resource related to wayfinding signage).

Heuristic Evaluations

We conducted heuristic evaluations of 11 islands in Second Life. These spaces were selected to:

- cover a range of disciplines, such as, computing, genetics, and marine science;
- support a range of learning activities; and
- provide variety in approaches to aiding navigation and wayfinding, for example, landmarks, maps, paths, signs, camera controls, and teleportation.

There was also a logistical constraint; we chose those islands where we felt there was a potential to carry out interviews with the designers and educators, and/or to seek permissions from the island owners for pictures and to visit their islands with the participants (students) for user observations. The primary focus of the NAVY project was navigation and wayfinding, therefore, seven of the eleven islands were evaluated specifically in relation to navigation and orientation support (HC9). We also wanted to know how designers of commercial Second Life islands guide a visitor to shopping locations. We evaluated LE LOOK, a non-educational Second Life island selling avatar accessories, for its navigational and wayfinding characteristics.

We, the two researchers on NAVY, performed the role of “expert evaluators” and conducted independent heuristic evaluations. We conducted two types of heuristic evaluation: exploratory walkthrough and task-based walkthrough. An exploratory walkthrough involved a usability evaluation without any specific tasks to guide the evaluation process. In conducting the exploratory walkthroughs, we used a variant of heuristic evaluation. As well as identifying usability defects, we also noted positive adherence to the heuristics, as our aim was to identify examples of good design practice. A task-based walkthrough involved an evaluator identifying usability defects whilst conducting learning activities that a student/visitor would be expected to perform.

User Observations

In approaching navigation and wayfinding issues, designers need to pay attention to how people perceive and understand an environment, how they situate themselves in spaces, and how they use information about the environment in the decision-making and decision-execution processes (Arthur & Passini, 1992). Therefore, conducting user observations alongside heuristic evaluations in NAVY was the optimal way for us to balance expert-based reviews by eliciting end-user navigational experiences and wayfinding strategies.

For each of the islands that investigated, we designed a set of learning activities for user observations. These were a subset of the activities that the designers and educators of that island were expecting the visitors or students to perform. Further, the learning activities encompassed one or more of the Second Life navigational aids (NAV) listed in Table 1.3. The list of NAVs was compiled from the literature review and the results of conducting exploratory walkthroughs in Second Life.

Table 1.3 Second Life Navigational Aids

Navigational aid	Description
NAV1	<i>Architectural landmarks:</i> A significant physical feature of the environment which is memorable.
NAV2	<i>Camera control:</i> A tool with which an avatar can view parts of an island in Second Life from a variety of angles without having to move.
NAV3	<i>Directional signs:</i> Signs with or without arrows that specify the direction of a location, object, or event.
NAV4	<i>Flying:</i> In an island of Second Life, moving through the sky like a bird without the need for wings.
NAV5	<i>Identification signs:</i> Signs in verbal and/or non-verbal forms that identify a place or object. Unlike directional signs, identification signs mark destinations rather than directions.
NAV6	<i>Maps:</i> A visual representation of an area showing the relationships between elements of that space, such as objects and regions.
NAV7	<i>Notecards:</i> An item of text and/or embedded images, textures etc., that can be stored, retrieved, and transferred between avatars.
NAV8	<i>Paths:</i> A channel movement such as a railroad, street, or walkway.
NAV9	<i>Second Life landmarks:</i> A Second Life precise location which can be stored and used to teleport from another location.
NAV10	<i>Sensors:</i> A device that can detect an avatar's movement in a given area of an island in Second Life.
NAV11	<i>Structure of the island:</i> The overall form or organization of an island in Second Life.
NAV12	<i>Teleporters:</i> A device used for teleportation.
NAV13	<i>Teleport maps:</i> A visual representation of an area that can also be used as a device for teleportation.

As an illustration, in Table 1.4, we have listed some of the learning activities in The Abyss Observatory, a marine science museum in Second Life.

Table 1.4 Examples of Learning Activities for the Abyss Observatory and the Associated Navigational Aids

Learning activity	Associated navigational aids (NAVs)
Identify the purpose of the island: is it apparent how to find your way around? Is help available?	identification signs, maps, structure of the island, teleport maps
Discover what marine creatures and marine life exists at different depths of the ocean: e.g., in the area of “Journey into the Deep” find your way to the Microorganism Lab and observe the black smokers.	camera control, directional signs, identification signs, maps, paths, notecards
Find your way to the Research Ship “Okeanos Explorer” and collect a notecard describing its history.	architectural landmarks, camera control, flying, directional signs, notecards, identification signs, maps, paths, Second Life landmarks, structure of the island, teleporters, teleport maps

During user observations, we encouraged participants to think aloud (as if talking through their experiences to themselves). This enabled the researcher, who followed the participant as they went about conducting the learning activities (see Figure 1.4), to know if they were struggling to find a location/resource, or if certain navigational aids were well-designed and enabled the participants to find their way easily.



Figure 1.4 A user observation session with the researcher following the participant as the participant went about conducting activities on the island. Picture courtesy of the Vassar Island.

Following user observations, we held post-observation discussions (see Figure 1.5). During the post-observation session, the participants reflected on their experiences and we sought clarification for issues arising during the session. We encouraged the participants to share their other wayfinding experiences in Second Life to elicit examples of good and bad instances of navigational aids from other islands, and to also determine the navigational strategies that the participants prefer (for example, flying vs. teleporting or walking, use of maps vs. use of signs, and so on).



Figure 1.5 A post-observation session. Picture courtesy of the Vassar Island.

Each user observation session lasted approximately 45 minutes. The post-observation discussion with each participant took around 10–20 minutes. We audio-recorded the user observations and post-observation discussions.

Structured or Semi-Structured Interviews

We conducted inworld structured or semi-structured interviews with designers and educators. The questions enquired about the rationale for the design decisions of existing 3D learning spaces and sought their perceptions and examples of what contributes to usable designs. All the interviews, except for one where the educator chose to send us their response by email, were conducted inworld and on the island of the educator/designer who was being interviewed. This allowed interviewees to supplement the discussion by demonstrating pertinent features of the learning space (see Figure 1.6). We also conducted an interview with an educator who oversees the International Society for Technology

in Education (ISTE) Second Life group tours. The rationale for this interview was to investigate how navigational assistance can be provided for groups of avatars, and identify difficulties with navigating as a group.

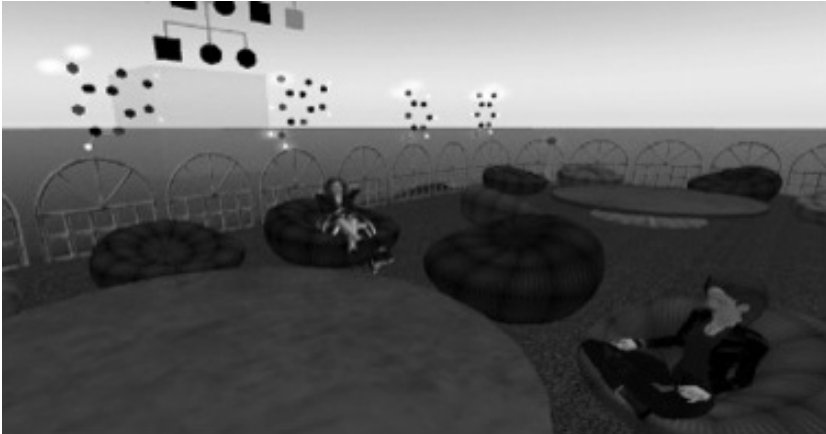


Figure 1.6 An interview with the designer of Genome Island. Picture courtesy of Genome Island.

We conducted inworld interviews in audio using Second Life voice chat, though in one case we used Skype since the participant had a low-bandwidth connection. One interview was conducted using Second Life's text chat as we felt that the interviewee would be more comfortable in that medium because of a language barrier. The issues of conducting empirical research in virtual worlds such as communication modalities (using text chat vs. voice chat in inworld interviews, or comparison of inworld interviews with face-to-face interviews), recruitment strategies, and how the anonymity of the medium demands a greater investment of time to establish a mutually beneficial relationship based on trust with the participants, et cetera, are described in detail in Minocha, Tran, and Reeves (2010), and Wadley, Gibbs, and Ducheneaut (2009).

Document Analysis

Document analysis (Gardin, 1973) involves analyzing the motivation, intent, and purpose of a document within a particular historical context. We collated documents related to a particular island by searching for papers and other online resources such as websites of the island, blogs, wikis, and videos/transcripts. The analysis helped us to understand the purpose of the islands and the intended

audience, which in turn helped us to design learning activities for task-based walkthroughs and user observations.

Research Ethics

We followed the guidelines of the British Educational Research Association (British Educational Research Association, 2011). The ethical implications for involving human participants, conducting inworld observations, and taking snapshots (pictures) in Second Life were considered, for example, using Linden Labs' policy for snapshots (Linden Research, 2011). We sought and gained approval from the Human Research Ethics Committee of the university (The Open University, Human Research Ethics Committee, 2013).

Data Analysis

We analyzed heuristic evaluation data in terms of the definition of usability (ISO, 1998):

- Positive aspects of navigation and wayfinding that enhanced user experience or facilitated task completion.
- Usability defects: obstacles such as inefficient completion of a task (it takes longer than necessary to complete), breakdowns, ineffectiveness (failure to achieve the task, or finding a venue or resource), or user dissatisfaction.

We applied thematic analysis (Thomas, 2006; Braun & Clarke, 2006) to identify themes emerging from transcripts of user observations, post-observation discussions, and interviews with designers and educators. We also used the technique to analyze the usability defects and positive aspects arising from task-based and exploratory walkthrough heuristic evaluations. Thematic analysis was suitable for the NAVY project because it provides a way of structuring and summarizing the findings from a diverse range of research techniques. It involves reading the raw data while being guided by the research questions to derive concepts and report patterns (themes). The primary purpose of the technique is to allow research findings to emerge from the frequent, dominant, or significant themes without the restraints imposed by structured methodologies.

Results

In this section, we present a subset of the data to demonstrate the analysis of the data collected during user observations and heuristic evaluations.

Positive Design Aspects that Aid Navigation and Wayfinding

Analyzing the positive aspects from heuristic evaluations and user-based observations revealed several themes based on key HCI and the usability principles of visibility, affordance, feedback, use of real-world metaphors, consistency, and structure. The themes and the corresponding guidelines are shown in Table 1.5.

Table 1.5 Guidelines Based on Positive Design Aspects that Aid Navigation and Wayfinding

Theme	Guidelines
Objects that are similar to real-world objects are easy to recognize	<ul style="list-style-type: none">• Consider the use of real-world metaphors• Consider using design features so that an area resembles a real-world space
Information to aid navigation should be easy to find and understand	<ul style="list-style-type: none">• Place key information at, or close to, the entry point• Place a map at the entry point to the island• Show the user's location on every map• Maps should be visible at a distance and be readable without the use of camera controls• Provide identification signs outside major locations• Provide identification signs to orient the user• Place key information at, or close to, the entry point• Place a map at the entry point to the island• Show the user's location on every map• Maps should be visible at a distance and be readable without the use of camera controls• Provide identification signs outside major locations• Provide identification signs to orient the user
Colour and formatting is important in the design of objects	<ul style="list-style-type: none">• Consider using bright colours to get a user's attention• Use consistent colours and fonts for maps and teleport boards• Make information on directional signs as concise as possible• Consider formatting textual information on maps and schematic diagrams to signify its importance
Audio or visual feedback to user's actions should be easy to notice and appropriate to match with the context	<ul style="list-style-type: none">• Give immediate feedback for user actions• Consider using a combination of audio and visual feedback• Consider the use of animated objects to get user's attention

Theme	Guidelines
Pathways and entrances should be easy to understand	<ul style="list-style-type: none"> • Ensure that paths are legible • Ensure that the approaches and entrances to places are legible • Consider the use of transition points on paths • Consider the use of path-defining elements, for example, by using textures to indicate the entrances and make them look different from the main circulation route

Design Features that Negatively Impact on Navigation and Wayfinding in 3D Learning Spaces

The themes or design features that cause obstacles or breakdowns during navigation and wayfinding and representative quotes from student-participants are presented below. The name of the Second Life island that a student participant is referring to is in square brackets at the end of the quote.

Theme: Learning spaces don't resemble real-world physical spaces

"I was unsure when I had reached the Library as I was expecting to see collections of books and a building resembling a real-world Library, similar to that on the OU [university] campus." [deep|think] (see Figure 1.7)

Theme: It is not obvious how to interact with an object

"I see this 3D map down here that says library. I click, but it doesn't let me click. This board called Library. I touch . . . I'm not sure how to teleport using this." [deep|think]

Theme: Functional areas of an island can be difficult to find or get to

"I don't know where the Explorium is. I am lost, really, so I am just wandering around trying to figure out where I am supposed to go." [The Abyss Observatory]

Theme: Navigational aids can be difficult to locate

"There is a sign that says Study Island. If the signpost was put a bit earlier that would be better, because I don't know until I actually reach it." [deep|think]

Theme: Navigational aids can be difficult to understand and use

“The schematic diagram shows some of the places where you can go but it’s not very clear exactly how that relates to where I am.” [The Abyss Observatory]

Theme: Help is not always easy to find

“I don’t know how to ask for help as I can’t think of anything obvious.”
[The Abyss Observatory]



Figure 1.7 Flow diagram of NAVY’s methodology.

Effects on Student Experience

Examples of the effects on student’s ability to perform learning activities due to difficulties in navigation and wayfinding and quotes from the student-participants follow.

Effect: Students may abandon the learning activity

“It was really confusing as there were no signs and I could not find my way around for love nor money so I just gave up in the end.” [The Abyss Observatory]

Effect: Learning activities will take longer than necessary

“I remember when going back to the teleport map I really had to think hard about how I had got there ... it was sort of like a maze for me to have to go back again.” [deep|think]

Effect: Students may return to the entry point to seek help

“Is there something in the deep|think Welcome area that tells me where the library is?” [deep|think]

Effect: Students may become frustrated or confused

“The notecard mentions Skypods and the link to Library Welcome Island . . . but if I select that I will end up back here (sighs) . . . oh.” [deep|think]

Effect: Students may wander aimlessly looking for their destination

“You just have to keep wandering around until you find what you’re looking for.” [Genome Island]

Effect: Students may make incorrect assumptions or may take a guess

“There’s a study area which is probably the Student Room, I’m assuming. I am going to go there and test.” [deep|think]

The impact on student experience and engagement in terms of the usability constituents of effectiveness, efficiency, and satisfaction (ISO, 1998) are many. For example, if students wander aimlessly looking for their destination, this will affect effectiveness and user satisfaction; if learning activities take longer than necessary, this will have a negative effect on efficiency; and if a student abandons the learning activity, this will result in a breakdown situation, or will affect efficiency, as the student expends additional cognitive and time resources.

The following design aspects resulted in breakdowns in the user-based observations:

- Locations did not resemble real-world physical spaces
- Key locations were not shown on maps or teleport maps
- Directional signs were missing or badly designed
- Identification signs were absent; it is not sufficient just to direct a user to a destination. A user must know when they have reached their destination by seeing identification signs
- Locations were not referred to consistently on information boards and in teleport maps

From each of the themes corresponding to positive aspects, usability defects, and breakdowns in the data, we have derived over 200 design guidelines (DGs). Each design guideline is supported by examples or user quotes from the data. A subset of guidelines is presented in Table 1.6.

Table 1.6 A Subset of Design Guidelines

ID	Design guideline
DG199	Locations of an island should be referred to consistently on information boards and teleport maps.
DG202	Provide maps of an island to orient the user.
DG203	Consider using help points to provide important navigational information.
DG204	Provide mechanisms for students to teleport within a learning space.
DG205	Consider incorporating Second Life landmarks in notecards to teleport within an island.
DG206	Incorporate visual aids in the form of signs and notices.
DG207	Consider that people use camera controls to look for things rather than walking around.
DG208	Replicate real-world objects for familiarity.
DG209	Consider that people tend to fly around in the absence of appropriate navigational aids.

A subset of the good practice design guidelines resulting from the thematic analysis of transcriptions from interviews with designers and educators is presented below with the identifying DG number followed by the design guideline. Quotes from the designers and educators follow the guideline.

DG183: Structure learning spaces by having different functional areas.

“Activities in Genome Island are organized into four main areas; The Abbey and Gardens, the Tower, the Gene Pool and the Cell Terrace.”
[designer, Genome Island]

DG184: Provide 3D models of an island to orient the user to the structure of the island.

“The 3D map is to help visitors to understand The Abyss Observatory and consists of 7 or 8 layers.” [educator, The Abyss Observatory]

DG185: Provide help by incorporating introductory tours, quests, tutorials, and scavenger hunts.

“The tour was intended to give a quick overview of Genome Island and a little bit about each area. You can get off at each point before continuing the tour.” [designer, Genome Island]

DG187: Provide help by incorporating information points, notecards, Second Life landmarks, and links to Web resources.

“We provide notecards with locations and Second Life landmarks you can use to teleport to places in deep|think. I don’t think anybody actually walks . . . it is such a big development that people just get a map out and use that to just teleport to each part of the island.” [designer, deep|think]

DG188: Provide support for group tours on an island.

“When conducting ISTE group tours, my favourite teleport device is a very clear board. One that’s large, with big squares on it that multiple people might be able to hit at the same time. I don’t mean they have to be able to teleport at the same time, but when there is a big crowd of people around the teleport board and it has a tiny ball to hit with your mouse clicker that’s hard to do in a crowd. But, if it’s a nice big board with a picture and multiple people can touch it and zap off . . . that’s great.” [educator, ISTE tour group]

DG189: Provide support for educators to design guidance notes, learning activities, plan lessons, and plan tours.

“When I designed the tour of The Abyss Observatory, I had several aspects/criteria in my mind: time duration of the tour; and how easy it would be to move from one place to another with minimum walking and following around but through teleporting.” [educator, The Abyss Observatory]

DG190: Provide a range of mechanisms to support navigation.

“The principle of redundancy has been used. There is the 3D map of deep|think, there is the flat teleport map and there is, to some extent, the same information in Mary’s quest. Other examples like from the underwater theatre where you use the lift, the little teleporter or swim.” [designer, deep|think]

DG192: Apply lessons learned from the 2D or 3D virtual environments such as the Web, computer games, or existing Second Life learning spaces.

“Teleporters are sort of like hyperlinks. So, I did think about web navigation when designing Genome Island. They serve the same purpose as websites as they take you from place to place. Unfortunately, there is no backspace to take you back to your previous location.” [designer, Genome Island]

DG193: Incorporate design features with real-world similarities.

“We intend [for] The Abyss Observatory [to be] different from [a] real-life museum. And to make clear the difference, we arranged [the] usual museum and aquarium near the entry point. But about navigation, we should design [it] as [much as] possible [to be the] same [as a] real-life museum, because human behaviour is restricted by real life.” [designer, The Abyss Observatory]

DG194: Design 3D learning spaces in an iterative process involving evaluations with users and re-design.

“The scavenger hunt in Genome Island was fine-tuned over different classes.” [educator, Genome Island]

We have also derived best practice guidelines for navigation and wayfinding for each of the navigational aids listed in Table 1.3. Each best practice guideline is accompanied by an image from an island in Second Life to demonstrate the guideline and aid the designer to understand and apply it. Figure 1.8 illustrates one of the best practice guidelines for paths (NAV8 in Table 1.3): “Paths are channels for movement such as walkways. Transition points in paths should clearly demarcate two different areas. There are several examples in the Virtual Ability Island which show transition points and some of these are also designed as ramps for accessibility purposes.”

Design Changes in Second Life Islands as a Result of the Research Findings

Following our investigations, we presented summaries of our findings to the designers of the islands involved in our research. The summaries helped to sensitize designers to the usability defects and inform them about good practice in their designs from an HCI perspective. The designers modified their designs based on our feedback. For example, new directional signs have been added to Genome Island. Following the guideline “DG11: provide directional signs at decision points,” the usability defect of not having a directional sign at the intersection (see Figure 1.1) was removed by incorporating a signpost there (see Figure 1.9).



Figure 1.8 Library in the deep|think Island. Picture courtesy of the deep|think Island, Department of Computing, The Open University, UK.

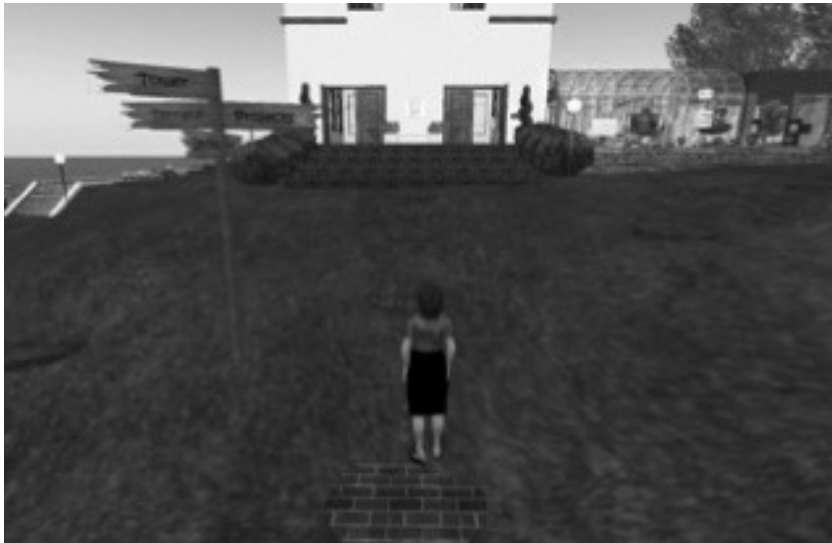


Figure 1.9 The transition point in the paths from grass to the wooden surface includes a ramp which can be useful for wheelchair users. Picture courtesy of the Virtual Ability Island.

The paths in the maps of Vassar Island have been modified, and the designers of Vassar Island are considering modifying some of the island’s directional signs based on our guidelines. The Abyss Observatory now features a revamped entry point, improved identification signs and teleportation devices, and the use of colour coding in directional signs and information boards (see Figures 1.10a and 1.10b). In the previous design (Figure 1.10a), there was no information at the entry point about the various displays in The Abyss Observatory, and only guided tours by the island owner (when he was around) could help uncover the possibilities. In Figure 1.10b, the entry point includes information for four guided tours showing different parts of Abyss. Now guided tours from the central hub help visitors explore the island on their own.

Discussion

In this section, we discuss some of the results of our research by contextualizing them within the literature related to the design of real-world navigational aids and web usability principles. The users’ comments in this section are indicated in double quotes and the name of the island is in square brackets.



Figure 1.10a Addition of directional signs at a decision point on an intersection. Picture courtesy of the Genome Island.



Figure 1.10b Re-designed entry point of The Abyss Observatory. Picture courtesy of The Abyss Observatory.

Maps and Signs

In real-world interactions, some people prefer maps to signs, and vice versa. However, in our research, we could not draw conclusions where people used the maps in Second Life the same way as they do in the real world, as the design of maps or 3D models in virtual worlds are significantly different. However, there is compelling evidence in our data that shows users' reliance on signs while navigating 3D learning spaces: "there are no directional signs to guide me to the library" [deep|think], "I'll go to the auditorium . . . which is in front of me . . . I can see the sign" [deep|think], "there's a sign for the Cell Terrace . . . so that was easy" [Genome Island].

Providing environmental information such as maps and signs at the appropriate place is a key aspect of wayfinding design (Arthur & Passini, 1992). However, adherence to this principle was lacking on every island employed in the user observations. For example, there was no map at the entry point of Genome Island, an absence of directional signposts at intersections in deep|think, no identification sign for the Explorium in The Abyss Observatory, and inadequate directional signposts in Vassar Island. Further evidence regarding the incorrect design and placement of signs was gathered in a user observation of deep|think: "they should've put the notice so we could see it from where we're standing because you can only see it's the Breakout Area once you've reached it."

User's Position on the Map

Another principle discussed by Darken (1995) is to show a user's position on maps, which helps to orientate them; adherence to this principle was evident in deep|think, The Abyss Observatory, and Vassar Island. In contrast, this was not evident on the 3D model of Genome Island: "one thing I would have hoped for is a 'you are here.'"

Redundancy of Navigational Information

The principle of redundancy in navigational information implies the use of multiple means to communicate the same information (Arthur & Passini, 1992). For example, a directional sign for a safari park may incorporate an image of an elephant and the textual description "Safari park." In the welcome area of deep|think Island, there is a 3D model and a teleport map that provide similar information. However, the 3D model may cause confusion because users expect to interact with it and use it for teleportation, but it is just a representation and is not interactive.

However, it helps to bear in mind that although redundancy is an important principle and can support diverse navigational styles or strategies that different users employ depending on their choices and skills, using several navigational mechanisms (e.g., signs, landmarks, maps, etc., listed in Table 1.3) can clutter the space and cause information overload. We have noted in our empirical investigations that designers and educators are increasingly adopting a user-centred design approach: trying out designs, evaluating them with students, and then re-designing and improving them based on the feedback. A user-centred design will help ensure that learning spaces are optimized in terms of navigational and wayfinding support to suit the interaction preferences of users, and enable users to effectively process the information presented and to find their way around.

Navigational Strategies

We observed that while navigating to a location, teleportation was the logical first choice of all participants: "I am always looking for a teleport map" [The Abyss Observatory], "I prefer things that take you there straight away . . . teleport things" [The Abyss Observatory], "my preference is to use teleports if I know where they are" [Genome Island], "teleporting makes life a lot easier" [Genome Island]. We noted that if users couldn't easily access a teleport device or Second Life landmark, their wayfinding strategy was to either fly or wander around.



Figure 1.11a The seven pillars of wisdom outside The Open University's library on the virtual campus. Picture courtesy of the Media Relations Office, The Open University, UK.



Figure 1.11b The seven pillars of wisdom outside The Open University's library on the virtual campus. Picture courtesy of the deep|think Island, Department of Computing, The Open University, UK.

Architectural Landmarks

Genome Island provides fine examples of architectural landmarks (the ethos and significance of architectural landmarks in 3D spaces is discussed in Charitos, 1997), such as the Abbey and Tower, which are effectively used to direct students to activities and resources in the instructions. On the deep|think Island of The Open University, UK, the real-world architectural landmarks have been replicated in Second Life (see Figures 1.11a and 1.11b). On the island, there are seven pillars of wisdom that serve as architectural landmarks for locating the library. On the real-world campus of the university, these seven pillars are situated outside the library, and students, even though they study at a distance, may have come across pictures of the library in university communications—replicating them in the virtual space adds to its familiarity and comfort.

Suitability of Navigational Aids

Second Life navigational aids were introduced in Table 1.3. Following analysis of the data in NAVY, Table 1.7 provides a summary of related design considerations for navigational aids.

Table 1.7 Navigational Aids and Design Considerations

Navigational aid	Design consideration
NAV1: Architectural landmarks	Architectural landmarks such as a tower or auditorium can easily be located by users and serve as reference points.
NAV2: Camera control	Controlling the Second Life camera is a skill that users find difficult to master, but it provides a valuable navigational aid. The zoom function allows users to view parts of an island without having to walk. The camera’s view can also be rotated, allowing users a 360-degree view of parts of an island without moving.
NAV3: Directional signs	Directional signs at intersections provide navigational assistance where walking is required, or preferred, by visitors. The design, number, and placement of directional signs should be considered to aid legibility, readability, and decision-making.
NAV4: Flying	If insufficient navigational aids are available, the most common wayfinding strategy adopted by users was to fly. This was particularly true of experienced users of Second Life. Therefore, consider including architectural landmarks (see NAV1) to orient users, and make buildings open and easily accessible.

Navigational aid	Design consideration
NAV5: Identification signs	Identification signs should be given for key locations or buildings as they inform users they have reached their destination. If a location is not identified, users can become disoriented and make incorrect assumptions. Identifications signs should be visually accessible and consistently designed.
NAV6: Maps	Maps play an important role in showing how users can identify and move between their current location and a destination. They should be easy to read and include architectural landmarks, paths, and key locations. Not all users understand or like to use maps. Maps should be placed close to the island's entry point. On complex islands, consider the use of additional maps at landing points for sub-sections of the island.
NAV7: Notecards	Give consideration to information included in notecards. Second Life landmarks embedded in notecards are frequently overlooked or become lost within a user's inventory. This is particularly true of inexperienced Second Life users. Label the notecard so that it is obvious what it contains and make the content easy to follow.
NAV8: Paths	Some users of Second Life like to walk and use paths. Paths should be designed so they are legible and articulated. Winding pathways and narrow corridors should be avoided as this can restrict avatar manoeuvrability.
NAV9: Second Life landmarks (similar to bookmarks in websites)	The use of landmarks varies considerably based on users' experience and personal preference; do not automatically consider them the preferred method for teleportation.
NAV10: Sensors	Sensors: A device that can detect an avatar's movement in a given area of an island in Second Life.
NAV11: Structure of the island	Structure of the island: The overall form or organization of an island in Second Life.
NAV12: Teleporters	Teleporters: A device used for teleportation.
NAV13: Teleport maps	Teleport maps: A visual representation of an area that can also be used as a device for teleportation.

Designing Entry Points of Islands in Second Life

Users' first impressions of real-world or virtual environments greatly influences their perceptions and attitudes. An impression is largely formed at the entry

point, that is, a point of intentional entry into a space. Also, the user observations in NAVY have shown that visitors often return to the entry point of an island when they encounter wayfinding difficulties; they expect the entry point to be a source of help, just as website users return to the home page if they are unable to find their way around the website.

The principles of design of home pages on the Web can be applied to the design of entry points in 3D virtual worlds, for example (based on Lidwell, Holdern, & Butler, 2003):

- *Minimal barriers*: remove barriers by ensuring it is clear how a visitor can interact with objects; do not use unfamiliar terminology; incorporate features that are similar to real-world physical spaces.
- *Points of prospect*: use points of prospect to orient the user and provide options for navigation. For example, make it obvious what the learning space is about, use directional signs, maps, meaningful graphics, teleporters, and notecards containing Second Life landmarks.
- *Progressive lures*: incorporate progressive lures such as the tours on Genome Island and Vassar Island, or the introductory video given on deep|think. Other types of progressive lures are the use of entry-point greeters, or a visual display of popular destinations such as a teleport map just beyond the entry point.

Research Outcomes

The empirical research in the NAVY project has demonstrated that while navigating and wayfinding in 3D virtual learning spaces, users employ a combination of real-world navigational and wayfinding mechanisms (e.g., walking, using signs, and maps), and those of 3D virtual environments (e.g., teleporting, flying). Their choices and decisions are also influenced by real-world experiences of navigating and wayfinding, and also depend on interactions with websites. Teleportation was the most commonly used method to move around in Second Life. However, having found a teleport device, users were not always sure how to interact with it for a variety of reasons, for instance, due to lack of visual feedback. If teleportation wasn't possible or teleporters couldn't be found, a user resorted to flying or walking. Although the usage of real-world navigational aids such as maps, paths, and signs is evident in the designs of learning spaces, we have noted that designers have incorporated elements of web design, particularly in the design of entry points and navigational mechanisms from the entry point.

The key research outcomes of the NAVY project include: (a) 104 heuristics for the design of 3D learning spaces, 43 of which are specifically related to navigation and wayfinding; (b) over 200 design guidelines yielded by thematic data analysis; (c) exemplars for the 20 best practice guidelines for the design of 3D learning spaces; (d) the identification of 13 Second Life navigational aids, their suitability for use in 3D learning spaces analyzed and contextualized in the literature related to HCI, web usability, and real-world navigation; and (e) how the principles of entry-point design for a website could be applied to the design of entry points in 3D learning spaces.

Although the NAVY project was carried out in Second Life, it is hoped that the findings from our research will be applicable to other avatar-based virtual worlds. We are in the process of setting up a website to disseminate the design guidelines and heuristics, and to obtain feedback on the usability, comprehensibility, and usefulness of our research outputs from educators and designers.

The research findings from the NAVY project have implications for several audiences:

- Designers of 3D learning spaces
- Educators using learning spaces for teaching
- Students interacting with learning spaces
- Researchers of virtual worlds.

Designers of 3D learning spaces: A key contribution of this research project has been to develop a toolbox of heuristics and guidelines for designers.

Educators and students: The design guidelines for improving the usability of learning spaces will benefit educators and students through enhanced engagement, for example, reducing obstacles to learning by making resources more accessible.

Researchers: The methodology in NAVY involved the use of pre-interview information sheets, user observations, think-aloud protocols, and retrospective protocols. Overarching this methodology were the ethical implications of conducting research in virtual worlds. Previous empirical research in Second Life by Minocha et al. (2010) involved interviews and focus groups. The methodology in this project extended their methodological approach and toolbox of techniques by utilizing heuristic evaluations and user observations. Further, we have shown how a combination of research techniques can provide insights from different perspectives. Although designers and educators provided the basis and rationale

for their designs in our interviews with them, user observations with students and heuristic evaluations were used to assess the actual design.

Future Directions and Conclusion

Navigational strategies and how they may change over time: Although we elicited the navigational strategies and preferences of the participants, we did not delve deeper into how these navigational preferences were developed and how the preferences and strategies may have changed over time. It is quite possible that as users' skills with the Second Life interface develop, or they became more familiar with the 3D virtual environments, they employ different navigation strategies. It would be worth investigating how these user-navigational strategies develop and change over time. Such an investigation will help inform educators and designers about the design of activities and learning spaces, respectively, to support a variety of navigational strategies and preferences of their students and to cater for, in their designs, the possible changes that may occur over a period of time.

Quantitative data analysis: One limitation of our research is that although we gathered qualitative data of NAVY problems and their possible aspects on usability and user experience, we did not gather quantitative data such as, "it took X minutes of time to reach a location because of the absence of signage. When directional or reassurance signs were positioned at the correct places, for example, at decision points or to reassure, it took Y minutes. Task performance was therefore improved as $Y < X$." In Second Life or other 3D virtual environments, it is generally straightforward to perform such comparison studies as one can add or remove objects without much effort, for example, by dragging and dropping from the designer's inventory.

Developing usability metrics to study wayfinding performance: Ruddle and Lessels' (2006) study of wayfinding in virtual environments identified three levels of metric: users' task performance, physical behaviour, and decision-making rationale. Within the users' task performance category they identified three metrics: time taken; distance travelled and the number of rooms entered; and number of errors or correct turns. One consideration for future research could be to apply and extend Ruddle and Lessels' set of usability metrics for wayfinding performance in 3D learning spaces.

Evaluating wayfinding strategies in real-world simulations of architectural structures: A virtual world can provide a cost-effective environment to develop models

or simulations of physical learning spaces and to observe the stakeholders' interactions with these simulations and elicit their experiences (e.g., Pathmeswaran, Ahmad, Rooke, & Abbott, 2010). These evaluations could provide insights to the architects and designers about how the spaces being designed will be used in real life and changes that are required to improve them. Thus, it would be worth investigating the effectiveness and efficiency of 3D virtual worlds such as Second Life and our set of guidelines and heuristics for designing and evaluating architectural designs before they are built in real life.

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